Evaluation of Intrarenal Blood Flow by Doppler Ultrasonography Immediately After Extracorporeal Shock Wave Lithotripsy on Hydronephrotic Kidney

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Extracorporeal shock wave lithotripsy (ESWL) is an effective and relatively noninvasive mode of treatment for urinary calculi. The aim of this study was to test whether therapeutic ESWL induces changes in renal parenchymatous blood flow and to evaluate shock wave side effects on the renal parenchyma. A total of 45 patients who underwent ESWL for ureteropelvic stone between January 2002 and July 2003 were included in this prospective study. Color Doppler sonography before and 30 minutes after ESWL showed no significant morphologic change. Resistive index (RI) was used to estimate renovascular resistance. The RI significantly increased in obstructed hydronephrotic kidneys. However, no significant change was observed in both treated and untreated kidneys before and after treatment. Hydronephrotic kidneys do not have a higher risk of post-ESWL renovascular resistance interference. The measurement of changes in RI with Doppler ultrasonography may provide useful information for clinical diagnosis of renal tubulointerstitial and vascular damage.

Key Words: shock wave, resistive index, urinary obstruction
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Extracorporeal shock wave lithotripsy (ESWL) has emerged as an effective and relatively noninvasive mode of treatment for a variety of urinary calculi. Many authors have noted the appearance of acute renal damage by shock waves, including subcapsular or perirenal hematomas [1], and increased serum creatinine, lactate dehydrogenase, creatine kinase, and alanine succinic transferase [2,3]. It has been suggested that lowering the energy generation may be advantageous in minimizing the degree of renal damage in children. Elderly patients also have a higher risk of post-ESWL renal-tissue damage than younger patients [4].

Color Doppler ultrasonography has proved to be an effective, noninvasive method for evaluating renal vascular function. It can be used to measure blood flow velocity in the renal circulation within small parenchymal arteries. Because it is measured in an artery in the renal parenchyma, the resistive index (RI) measured by Doppler ultrasound is used to evaluate vascular resistance and is elevated in diseases involving the tubulointerstitial or vascular system.

Experimental studies of ureteric obstruction in dogs have shown an increase in RI, after ureteric obstruction that reaches diagnostic sensitivity in obstructed kidneys, after 3 to 4 hours [5–8]. Doppler ultrasound studies in patients with obstructed kidneys and in normal subjects indicate that the normal RI is less than 0.7, and that the

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increase in RI in obstructed kidneys can be used to distinguish dilated obstructed kidneys from dilated unobstructed ones. However, the generally accepted upper limit of 0.7 for renal RI is exceeded in patients entering their seventh decade, who have a greater risk of post-ESWL renal vascular damage [9].

Ureteral obstruction increases ureteral pressure, decreases renal blood flow, and leads to interstitial fibrosis. However, the acute changes in renal function and parenchymal damage following ESWL in patients with hydronephrotic kidney are rarely discussed. Therefore, we performed a prospective study of RI changes before and after ESWL in order to determine whether or not there are any renovascular resistance alterations attributable to ESWL in a hydronephrotic kidney.

Materials and Methods

Between January 2002 and July 2003, 208 patients with acute-onset renal colic went to the emergency department of our hospital. Patients diagnosed with a ureteropelvic junction stone were enrolled in the study. Exclusion criteria included acute pyelonephritis, horseshoe kidney, deformed renal calyces, and chronic renal parenchymal disease, such as diabetes mellitus. The diagnosis of ureteropelvic junction stone was confirmed by abdominal X-ray, excretory urography and ultrasound studies. Overall, 45 patients treated with unilateral ESWL for urolithiasis were enrolled and 90 kidneys were examined with Doppler ultrasound. Patient age ranged from 21 to 66 years (mean, 47.5 years).

ESWL was performed using a Siemens Lithostar multiline lithotripter (Siemens Medical, Munich, Germany) at a frequency of 2/sec under intermittent fluoroscopic guidance, until disintegration of the calculus. The average number of shock waves was 3,226 (range, 1,600–3,500). The electrical discharge ranged from 13.7 to 15.1 kv (mean, 14.23 kv). The mean total energy applied (electrical discharge × number of shocks) was 46,022 kv/patient (range, 21,440–51,450).

Doppler ultrasonography was performed immediately before and 30 minutes after ESWL. We used the Toshiba Model UZRI 345A system (Toshiba Medical Systems Corp, Tokyo, Japan) with a 3.5-MHz convex Doppler probe. Before and after ESWL, three different measurements were taken in the treated kidney along the shock wave blast path by pulsed wave Doppler ultrasound. The readings were obtained at an interlober or arcuate artery traveling in the lower pole of the kidney. The interlober artery was localized with the help of color Doppler sonography. The artery had to be clearly visible over a distance of at least 1 cm. Vascular resistance was determined at an artery of the renal parenchyma with the help of pulsed wave Doppler ultrasound. To eliminate the problem of angle correction, the RI was calculated using the equation:

$$\text{RI} = \frac{\text{systolic peak velocity} - \text{end diastolic peak velocity}}{\text{systolic peak velocity}}$$

The contralateral kidney, which served as a control, was assessed using the same protocol. All examinations were performed by the same highly experienced sonographer. As Knapp et al reported that there is an age-related correlation between post-therapeutic RI increases and patient age [9], patients were stratified as younger (< 55 years) and older (≥ 55 years). In nine patients, a follow-up Doppler ultrasonographic study was performed 1 month after ESWL.

The values obtained before and after treatment were analyzed statistically using the paired Student t test. A p of less than 0.05 was considered statistically significant. Results are presented as mean ± standard deviation.

Results

Perioperative data

A total of 45 patients were treated with unilateral ESWL. Mean duration of treatment was 60 minutes. The mean creatinine level before ESWL was 1.55 mg/dL (range, 1.2–2.25 mg/dL) and the mean stone size was 1.24 cm (range, 0.6–1.7 cm).

Morphologic evaluation

There was no statistically significant difference between the renal dimensions – length, width, anteroposterior diameter, and parenchymal thickness – before and after treatment (Table 1).

Changes in RI before and after shock wave lithotripsy

The changes in the RI values for the 90 kidneys before and after ESWL are shown in Table 2. The mean RI was significantly different between the pretreatment kidney (0.65 ± 0.057) and contralateral kidney (0.60 ± 0.051; $p < 0.001$). Older patients had significantly higher RI (0.63 ± 0.069) in contralateral kidneys at baseline than younger patients (0.59 ± 0.044; $p = 0.021$). A comparison of the mean

Table 1. Kidney dimensions, length (L), width (W), anteroposterior diameter (AP) and parenchymal thickness (P) (cm ± standard deviation), before and after extracorporeal shock wave lithotripsy

	Before treatment	After treatment	*p*
L	10.9 ± 0.9	11.0 ± 0.9	0.324
W	5.5 ± 0.6	5.7 ± 0.6	0.406
AP	4.9 ± 0.6	5.1 ± 0.6	0.345
P	2.1 ± 0.3	2.1 ± 0.3	0.453

Table 2. Resistive index in different age groups before and 30 minutes after extracorporeal shock wave lithotripsy

	n	Before treatment	After treatment	*p*
Treated kidney				
Total	45	0.65 ± 0.057	0.66 ± 0.054	0.467
< 55 yr old	31	0.64 ± 0.047	0.64 ± 0.038	0.693
≥ 55 yr old	14	0.69 ± 0.081	0.69 ± 0.062	0.241
Contralateral kidney				
Total	45	0.60 ± 0.051	0.62 ± 0.049	0.405
< 55 yr old	31	0.59 ± 0.044	0.59 ± 0.024	0.511
≥ 55 yr old	14	0.63 ± 0.069	0.67 ± 0.067	0.335

RI before (0.65 ± 0.057) and after (0.66 ± 0.054) ESWL showed no significant increase in the treated kidney ($p = 0.467$). The contralateral kidney also showed no significant change in RI before and after ESWL ($p = 0.405$).

Clinical outcome

No serious complications of ESWL were encountered other than colicky pain in some patients during fragment discharge. Of the patients, 30 (66.7%) were stone-free and eight had residual fragments less than 4 mm in diameter after 3 months of follow-up.

Discussion

Although the low morbidity of ESWL has been repeatedly demonstrated in experimental and clinical studies, its possible adverse effects on the kidney are still being investigated. Hematuria is a universally short sequel of treatment. The trauma to the renal parenchyma associated with ESWL ranges from mild contusions to large hematomas associated with sufficient bleeding to require blood transfusions [1,10–12]. Kaude et al used magnetic resonance imaging (MRI), excretory urography, and radionuclide renal function test immediately after ESWL to demonstrate morphologic abnormalities in 74% of 38 treatments in 36 kidneys in 33 patients [1]. The MRI characteristics of the abnormalities immediately after treatment ranged from subcapsular hemorrhage to interstitial edema.

Studies performed in dogs have identified acute and chronic intraparenchymal and perirenal hemorrhage after ESWL, and interstitial edema is common along the shock wave blast path. The number and size of hematomas were directly related to the shock wave numbers administered to the kidney [12]. We performed ESWL for ureteropelvic junction stone with acute renal colic and evaluated the kidney along the shock wave blast path. However, we detected no morphologic changes in the kidneys using conventional gray scale ultrasound.

Acute unilateral ureteral obstruction results in a complex sequence of changes in renal blood flow and ureteral pressure. Ipsilateral renal blood flow and ureteral pressure have a triphasic relationship during the first 24 hours of acute unilateral ureteral obstruction [13]. In the first 2 hours, renal blood flow increases because of afferent arteriole vasodilatation, and the ureteric pressure increases. From 2 to 6 hours after obstruction, renal blood flow decreases secondary to vasoconstriction of the efferent arterioles, and ureteric pressure remains elevated. Subsequently, from 6 to 18 hours, renal blood flow remains reduced because of vasoconstriction of the afferent arterioles, and ureteric pressure decreases [13,14].

The recent refinement of color Doppler sonography has made it possible to examine the intrarenal vascular bed (i.e. the interlobar and arcuate arteries), to calculate the pulsatility index or RI, and to compare indices between the two kidneys. The RI is a physiologic parameter reflecting the degree of renal vascular resistance and intrarenal edema, which occurs in transplant rejection, acute tubular necrosis, and obstructive pyelocaliectasis.

RI correlates with the degree of obstruction. Shokeir et al have reported that, after the induction of ureteric obstruction in dogs, there is a progressive decrease in effective renal plasma flow (ERPF) and a progressive increase in RI of the kidney at the end of the first and second weeks of obstruction, with an almost stable value thereafter [15]. They also showed that the more severe the obstruction, the greater the increase in RI and the decrease in ERPF. An RI cut-off value of 0.7 provides a sensitivity of 92% and a specificity of 88% in distinguishing an obstructive from a non-obstructive dilated upper urinary tract [16]. The accuracy of this discriminatory value of RI can be improved by evaluating the contralateral kidney, especially in acute obstruction. Our study showed that RI is significantly different in the obstructed kidney and contralateral kidney ($p < 0.001$), though the RI in the obstructed group did not exceed the cut-off value of 0.7.

The present study also demonstrated no significant difference in the RI of treated kidneys before and 30 minutes after treatment with ESWL. Aoki et al demonstrated that the RI of treated kidneys significantly increased after ESWL [17]. They evaluated RI in 70 consecutive patients before and after ESWL with an EDAP LY-01 lithotriptor. Follow-up Doppler study showed that the mean RI returned to pretreatment levels after 1 week. As a result of cellular infiltration and the edema formed around the peripheral branches of the renal arteries, perivascular tissue thickening may occur and vascular resistance may therefore increase [17,18]. However, Beduk et al reported no significant difference in RI of the renal vessels before and after treatment using a Dornier MPL 9000 lithotriptor (Dornier MedTech, Munich, Germany) [19]. These different results may depend on a number of factors, including the type of lithotriptor used, total energy of shock wave delivered, prelithotripsy renal function, and timing of RI measurement.

It is now generally accepted that RI is an age-dependent parameter. Bude et al showed that RI in patients older than 60 years tends to be higher than in younger adults [20]. Knapp et al reported a positive linear correlation between patient age and post-ESWL changes in RI [4,9]. They proposed that the same amount of energy is not tolerated as well by the renal vasculature of elderly individuals as by that of younger patients. The present study also showed that elderly patients (≥ 55 years) had higher baseline RI than younger patients. This phenomenon may be attributed to a loss of elasticity of renal tissue and intrarenal vessels.

Shokeir et al reported that reversal of a previously elevated RI could be used as an early indicator that recovery of ERPF is likely [7]. They evaluated RI and ERPF in partial ureteral obstruction in dogs. Relief of obstruction was associated with normalization of RI and recovery of ERPF to near-normal basal values. In our prospective study, elevated RI in the obstructed kidney indicated increased renovascular bed resistance after urinary obstruction. We postulate that ESWL may increase post-therapeutic RI in hydronephrotic kidney because of an increase in renovascular bed resistance after urinary obstruction. However, we found no significant difference in RI in renal lower pole vessels before and after treatment of hydronephrotic kidney. We propose that ESWL treatment for ureteropelvic junction stones may relieve ureteral pressure. The balance between increased intrarenal perivascular edema and decreased ureteral pressure may contribute to these results.

Conclusion

We evaluated the acute functional and morphologic changes induced by piezoelectric lithotripsy. No significant morphologic change was encountered before and after ESWL treatment. Elderly patients had higher baseline RI than younger patients and the RI significantly increased in obstructed hydronephrotic kidneys. Hydronephrotic kidneys do not have a higher risk of post-ESWL intrarenal blood flow interference. Color Doppler sonography appears to be a safe, noninvasive, and reliable means of evaluating kidneys subjected to ESWL. The measurement of changes in RI with Doppler ultrasound techniques after ESWL may provide useful information about vascular and tubulo-interstitial damage.

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都卜勒超音波評估接受體外震波碎石術後腎水腫之腎臟內血流的立即變化

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體外震波碎石術已經成為治療腎臟結石一種有效且較無侵略性的方法。本研究的目的在於測試體外震波碎石術是否會造成腎臟實質血流的改變，而間接指出震波碎石是否會對於腎臟實質造成副作用。本研究包括 45 位患者，於 2002 年一月至 2003 年七月，因為腎盂輸尿管交接處結石而接受體外震波碎石術的治療。以彩色都卜勒超音波，在接受體外震波碎石術之前以及術後 30 分鐘後為患者作患側以及對側腎臟的檢查。在形態上，術前和術後並沒有明顯的變化。阻力指標以及搏動指標可以評估腎臟血流的阻力，在阻塞性積水的腎臟有明顯的升高。然而在接受治療以及未接受治療的腎臟治療前後則無明顯的變化。積水的腎臟並不會增加體外震波碎石術對腎臟組織受傷的危險性。利用都卜勒超音波的技巧測量阻力指標，也許可以對於臨床上診斷腎臟組織受傷提供一個有用的資訊。

關鍵詞：震波碎石，阻力指標，尿路阻塞

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